

Suppression of Tarnished Plant Bugs (Heteroptera: Miridae) in Cotton by Control of Early Season Wild Host Plants with Herbicides

G. L. SNODGRASS,^{1,2} W. P. SCOTT,¹ C. A. ABEL,¹ J. T. ROBBINS,³ J. GORE,¹ AND D. D. HARDEE¹

Environ. Entomol. 35(5): 1417–1422 (2006)

ABSTRACT Broadleaf weeds found in marginal areas by fields, roads, and ditches were controlled with herbicides in 23-km² areas of the Mississippi Delta in March or April of 1999, 2000, and 2001. There were two treated and two untreated 23-km² areas in each of the 3 test yr. The herbicides used were Trimec® or Strike 3™, and both contain mecoprop, 2, 4-D, and dicamba. Broadleaf weeds can serve as early season food and reproductive hosts for tarnished plant bugs, and population buildups can occur on these weeds before movement of plant bugs into cotton. Cotton fields in the treated sites and in untreated 23-km² sites were sampled for tarnished plant bugs weekly during June and July of all 3 yr. Overall mean numbers of tarnished plant bugs were significantly lower in cotton in the treated areas. The average reduction in overall mean numbers of plant bugs was 50% for the 3-yr period. Grower costs for insecticides used to control plant bugs were lower in cotton in the treated test sites in all 3 yr. The average net savings in plant bug control costs was estimated at \$35,477/yr for growers in the treated areas over the 3 yr of the study. Elimination of broadleaf weeds was found to be an effective method for reducing numbers of plant bugs in cotton. However, it did not reduce numbers of tarnished plant bugs in any year to a level in cotton where additional control with insecticides was not needed.

KEY WORDS tarnished plant bug, *Lygus lineolaris*, cotton, early season wild host plant

Tarnished plant bugs, *Lygus lineolaris* (Palisot de Beauvois), are controlled in cotton almost exclusively with insecticides. In the mid-South, control of tarnished plant bugs in cotton has become more expensive and difficult because of insecticide resistance. Populations in the delta of Arkansas, Louisiana, and Mississippi have become resistant to pyrethroid insecticides with lower levels of resistance to a cyclo-diene and several organophosphate insecticides (Snodgrass and Elzen 1995, Pankey et al. 1996, Snodgrass 1996, Hollingsworth et al. 1997). When eradication of the boll weevil, *Anthonomus grandis* Boheman, is completed in the mid-South, plant bugs will often be the main early season pest of cotton. Additional insecticide applications to control plant bugs will reduce benefits that growers have derived from boll weevil eradication and control of lepidopterous pests with transgenic cotton. Control methods for tarnished plant bugs not based solely on insecticides are needed.

The delta region of the mid-South is intensively farmed, and only a small area of the land is undisturbed by agricultural practices. Snodgrass et al. (1991) estimated that marginal areas near roads, fields, and ditches undisturbed by agriculture comprised only

2.4% of the land in a 6.4-km² area of Washington County, MS. In these marginal areas, broadleaf weeds are abundant and are used for food and reproduction by tarnished plant bugs in the winter and spring. As these weeds senesce, adult plant bugs move into cotton and other crops (Tugwell et al. 1976, Snodgrass et al. 1984). Management of wild hosts in marginal areas with herbicides could be economically feasible because of the small acreage involved. In addition, farmers in the mid-South in the mid-1990s widely adopted a weed control program in which winter and spring weeds are controlled in their fields with herbicides, mainly in February. This farming practice further restricts plant bugs in early season to the wild host plants available in the marginal areas not treated by the growers. Plant bug populations in the mid-South have also been affected by the increased production of corn, *Zea mays* L., and group IV soybeans, *Glycine max* (F.), over the past several years. Laboratory experiments have shown that corn could serve as a reproductive host for plant bugs when it flowers (Abel and Snodgrass 2004). Plant bug adults and nymphs can be collected from group IV soybeans when they bloom in May and June (G.L.S., unpublished data), but there is no published information on reproduction of plant bugs on soybeans. Both corn and group IV soybeans finish blooming during June and become unattractive to plant bugs, which migrate to wild hosts or cotton during late June and July.

Destruction of early season broadleaf hosts has been shown to be an effective method of reducing numbers

¹ Southern Insect Management Research Unit, USDA-ARS, Stoneville, MS.

² Corresponding author: SIMRU, USDA-ARS, PO Box 346, Stoneville, MS 38776 (e-mail: gsnodgrass@ars.usda.gov).

³ Delta Research and Extension Center, Mississippi State University, Stoneville, MS.

of tarnished plant bugs and their damage to apples and peaches (Killian and Meyer 1984, Atanassov et al. 2002, Hardman et al. 2004). Fleischer and Gaylor (1987) thought that management of two species of daisy fleabane (*Erigeron annuus* L. Persoon and *E. strigosus* Nuhlenberg ex Willdenow) could result in an effective areawide program for reducing plant bug numbers in cotton in heavily cropped agroecosystems such as the Highland Ridge area of northern Alabama. In this area of Alabama, roadsides can contain abundant numbers of plant bug hosts. Fleischer et al. (1989) studied management of two important wild hosts, *E. annuus* and *Daucus carota* L., along interstate right-of-way in the Highland Rim area over a 3-yr period. They found that a combination of mowing in June and August along with applications of the herbicide sulfomethuron methyl in June, August, and February effectively reduced populations of the two weed species during June to mid-July. These weeds normally harbor plant bug populations that could damage cotton during this time period. Mowing and use of herbicides are part of normal right-of-way maintenance of interstate highways in Alabama, and results of the study would be very useful in advising the Alabama State Highway Department on when and how to treat the right-of-way in an areawide program for plant bug control.

A large experiment was conducted in 1999, 2000, and 2001 to determine whether numbers of tarnished plant bugs found in cotton could be reduced by management of early season broadleaf wild host plants found in marginal areas near the cotton fields with a single herbicide application. The herbicide application used in the experiment was found to be very effective in reducing numbers of wild host plants and plant bug populations in marginal areas (Snodgrass et al. 2005). Results from the experiment showing the effect of the herbicide treatment on plant bugs found in cotton grown within treated areas are reported herein.

Materials and Methods

The experiment was conducted each year using four approximately square test sites that were 4.8 km on a side. In two of the test sites each year, a single application of Trimec 7® (PBI/Gordon, Kansas City, MO) in 1999 or Strike 3J™ (Agrilience, St. Paul, MN) in 2000 and 2001 was applied to most marginal areas with wild host plants during the first 2 wk of April 1999 and first 2 wk of March 2000 and 2001. These herbicides both contain mecoprop, 2,4-D, and dicamba and are effective in killing broadleaf weeds, thereby reducing reproduction of tarnished plant bugs in treated marginal areas (Snodgrass et al. 2005). These herbicides do not have activity on graminaceous weeds. The remaining two test sites (checks) did not receive the early season herbicide application each year. In 1999 and 2000, the two treated test sites were located near Tribbett and Dunleith in Washington County, MS, whereas the two check test sites were near Hollandale in Washington County and Kenlock in Sunflower County. The site

near Tribbett was used as a check site in 2001, whereas the second check site was located near Choctaw in Bolivar County. The two treated test sites in 2001 were located near Arcola and Hollandale in Washington County. All test sites were located at least 8t km apart in each year.

Cotton fields in all four test areas were identified in May of each year, and their location was marked on aerial maps of the test areas obtained from the Geographic Information Satellite Center at the Delta Research and Extension Center, Stoneville, MS. Each of the test sites were divided into quadrants for sampling purposes. Approximate field size was determined by determining row width and number in each field and by measuring field length with a vehicle odometer. Sample fields were chosen at random each week from those found in each quadrant of each test area. Fields were sampled weekly with 15–20 fields sampled each week from each of the four test sites. A total of 157, 185, and 212 fields were available in the four test sites for sampling in 1999, 2000, and 2001, respectively.

Sampling was by sweep net, and each sample was 10 sweeps with a standard (38 cm) sweep net swept back and forth across a single row of cotton. The number of samples taken per field was determined by field size and varied from 5 in small fields to 80 in large fields. Numbers of tarnished plant bug adults and nymphs captured were recorded in the field. Sampling began during the first week in June and ended during the last week in July. More than 10,000 samples were taken from cotton in each year of the study.

Insecticide use and cost data for plant bug control was obtained each growing season from growers in the treated and untreated sites. These data were used to calculate the average per hectare costs for plant bug control in cotton grown in the check and treated sites. The authors kept records on the amount of herbicide used, application equipment used, and labor costs. The number of hectares of marginal areas treated was calculated based on the amount of herbicide used and the application rate. The total cost of the herbicide treatment was calculated by an agricultural economist (Fred Cooke, Delta Branch Experiment Station, Mississippi State University, Stoneville, MS) each year, using the Mississippi State Budget Generator (Laughlin 1999).

Experimental design in each year was a completely random design with two replicates (areas) per treatment. There were several levels of subsampling: four quadrants within each area, 1–30 fields in each quadrant, 5–80 samples per field (10 sweeps/sample), and weekly samples for 8 wk each year. A preliminary analysis of variance (ANOVA) was performed on the data for each year by sample week and year. In the analysis, treatment was a fixed effect, whereas areas within treatment, quadrant within areas and treatment, fields within quadrant, areas, and treatment, and the residual of samples within fields, quadrants, areas, and treatments were random effects. Because there were only two treatments with two replications, there was not enough precision to test for treatment differences among weeks in each year. However, the anal-

ysis was used to identify the important sources of variability in the data. In the final ANOVA used on the data, year was treated as a fixed effect, and sample data were combined over weeks in each year and over all weeks in all years. Data were averaged over multiple samples per field to simplify the analysis, and total counts were transformed by $\log(x + 1)$ to satisfy assumptions of normality. Numbers of plant bugs found in fields grown in treated and check areas were compared by calculating the ratio formed by the mean number found in the fields in the check areas over the mean number found in the fields in the treated areas. Significance was determined using least significant ratio (LSR), which is equivalent to using least significant difference (LSD) on nontransformed data. Means shown in tables are geometric means obtained by taking the antilog of the log-transformed value. All analyses were performed with PROC MIXED (SAS Institute 1999).

Results

Estimated variance components from the preliminary ANOVA of the data showed that sample to sample variability (residual error) was always the largest source of variability in the data (an average 79% of the total variability). Field to field variability was also important and averaged 13% of the total variability. Quadrant variability and area to area variability were both small and averaged 5 and 3%, respectively, of the total variability.

Numbers of tarnished plant bugs found in cotton grown in the untreated areas were always higher than in cotton grown in the treated areas when sample data were combined over all weeks in a year or by week over all 3 yr (Table 1). This was also true for most weeks in the uncombined data, and the ratio (untreated/treated) was less than 1 in only 1 wk in 2000 and 2 wk in 2001 (Fig. 1).

Data were combined for analysis over weeks in the ANOVA because week did not interact with treatment (year \times treatment \times week: $F = 1.13$, $P = 0.37$, $df = 14,38$; week \times treatment: $F = 1.36$, $P = 0.25$, $df = 7,38$). Year also did not interact with treatment (year \times treatment: $F = 0.91$, $P = 0.45$, $df = 2,6$). The analysis showed that, averaged over all weeks and years, the numbers of plant bugs found in cotton grown in the untreated areas were significantly higher than the numbers of plant bugs found in cotton grown in the treated areas ($F = 6.17$, $P = 0.047$, $df = 1,6$). There was an average of 2.13-fold higher numbers of plant bugs in cotton grown in the untreated areas (Table 1). The mean number of plant bugs captured in cotton grown in the untreated areas per sample over all years was 0.16 compared with 0.08 per sample in cotton grown in the treated areas. The highest plant bug populations were found during 2001, averaging 0.28 and 0.20 per sample over all sample weeks in cotton grown in the untreated and treated areas, respectively (Table 1). The highest numbers of plant bugs were also found in cotton in the untreated and treated areas during the last 3 wk of July over the 3-yr period.

Table 1. Numbers of tarnished plant bugs found in cotton grown in treated or untreated 23-km² areas of the Mississippi Delta in 1999–2001

Year and week ^a	Ratio (untreated/treated)	Mean no./sample (10 sweeps) ^b	
		Untreated	Treated
1999	3.73	0.12	0.03
2000	1.83	0.13	0.07
2001	1.41	0.28	0.20
June			
First week	1.40	0.11	0.08
Second week	1.98	0.10	0.05
Third week	1.44	0.08	0.06
Fourth week	2.88	0.14	0.05
July			
First week	2.13	0.13	0.06
Second week	1.88	0.20	0.10
Third week	3.05	0.33	0.11
Fourth week	2.95	0.50	0.17
Overall	2.13 ^c	0.16	0.08

The treated areas received a single application of Trimec or Strike 3 herbicide in March or April to kill broadleaf weeds in marginal areas near fields, roads, and ditches.

^a Data are combined by year over all sample weeks and by week over the 3 yr; overall data are combined over weeks and years.

^b The means are geometric means obtained by taking the antilog of the $\log(x + 1)$ transformed data.

^c The overall mean no. of plant bugs found in cotton grown in the untreated areas was significantly higher than the mean no. of plant bugs found in cotton grown in the treated areas (LSR = 2.10).

Total costs for the herbicide applications were \$6,469, \$6,206, and \$6,411 in 1999, 2000, and 2001, respectively (Table 2). Totals of 314, 273, and 202 ha of marginal areas with wild hosts were estimated to have been treated to protect an estimated 2,409, 3,320, and 2,702 ha of cotton grown in the treated sites during the 3 yr. Expressed as a percentage of the 4,664 ha found in two 23-km² treated areas, 6.7, 5.9, and 4.3% of the total areas were treated in 1999, 2000, and 2001, respectively. The average cost per hectare for tarnished plant bug control with insecticides was lower for cotton growers in the treated sites in all 3 yr (Table 3). Growers in the treated sites spent \$15.98, \$19.29, and \$8.50 less per hectare in 1999, 2000, and 2001, respectively, than did growers in the check sites. The net savings in plant bug control costs in the treated sites were \$32,027, \$57,847, and \$16,556 in the 3 yr of the study.

Discussion

Tarnished plant bugs generally do not use a host for reproduction unless flower buds, flowers, or developing fruit are present (Snodgrass et al. 1984). Overwintering plant bugs mate and lay their eggs in wild hosts that bloom in the winter, and most overwintered adults are dead by mid-April. They produce new generation adults by mid-March in mild winters when winter hosts thrive and by mid-April in cold winters (Snodgrass 2003). The treatment of marginal areas with herbicide combined with control of winter and spring weeds in fields by growers produced large areas (23 km²) where few wild hosts were available to tar-

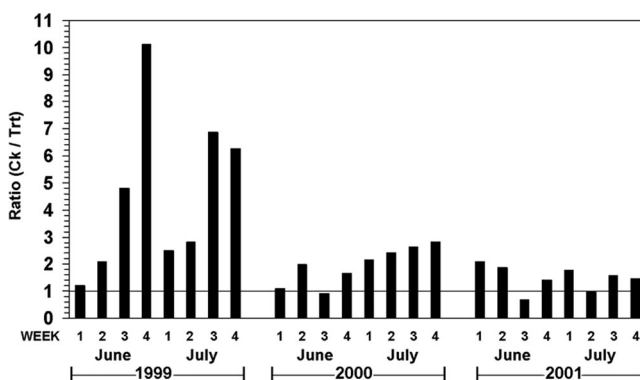


Fig. 1. Ratios of mean numbers of tarnished plant bugs found each week in cotton grown in untreated versus treated 23-km² areas of the Mississippi Delta in 1999–2001. The treated areas received a single application of Trimec or Strike 3 herbicide in March or April to kill broadleaf weeds in marginal areas near fields, roads, and ditches.

nished plant bugs in March to June. In the treated areas, the production of three to four new generations of plant bugs on wild hosts was greatly reduced. However, the presence of other crops that bloomed before cotton that were plant bug reproductive hosts may have influenced results in this study. The main crop planted in the treated sites that bloomed before cotton was group IV soybeans (blooms in mid-May through June). An estimated 242, 61, and 340 ha of group IV soybeans were produced in the treated sites in 1999, 2000, and 2001, whereas the corresponding amounts produced in the check sites were estimated at 170, 440, and 253 ha, respectively. Movement of adult plant bugs into cotton from soybeans as they finished flowering during the test was probable because the numbers of wild hosts available for plant bugs in the mid-South are at their lowest levels during July and August (Snodgrass et al. 1984), and cotton was the most abundant host available during these 2 mo. The importance of soybeans as a plant bug host is not known, and no estimates of their possible contribution to the plant bug populations found in cotton can be made. Another major agronomic crop grown in the mid-South is field corn. Laboratory experiments and field observations by agricultural consultants suggest that corn is an important reproductive host during June (Abel and Snodgrass 2004). However, only one small field of corn

was grown in the test sites during the 3 yr of the study. No studies showing the movement of plant bugs between crops in the mid-South are available. Sevacharian and Stern (1975) used fluorescent dust to show movement of *L. hesperus* Knight between alfalfa, *Medicago sativa* L., and cotton.

Reproduction of plant bugs on wild hosts, corn, and soybeans along with the decline in wild host numbers that occurs in July has made the tarnished plant bug a consistent pest of cotton in the mid-South in July and August. Increased numbers of plant bugs in cotton in July could also be caused by reduced insecticide use in cotton during June as the result of boll weevil eradication and the use of transgenic cotton to control lepidopterous pests. In this study, numbers of plant bugs captured in cotton were lower during June than in July in cotton grown in the treated and untreated sites. Mean numbers of plant bugs were also consistently higher in cotton grown in the untreated areas compared with mean numbers found in cotton grown in the treated areas over the 3 yr of the study (Table 1). The herbicide treatment greatly reduced numbers of wild hosts and the opportunity for short range migration of adult plant bugs produced on them into cotton in the treated sites in June and July. This reduction probably helped produce the lower numbers of plant bugs found in cotton in the treated sites. The

Table 2. Cost in dollars for treatment of marginal areas near fields, roads, and ditches in the Mississippi Delta with a single herbicide application in March or April

Year	Labor cost ^a	Herbicide cost ^b	Equipment cost ^c	Total cost	No. hectare marginal areas treated	No. hectare cotton protected	Trt. cost/ hectare cotton ^d
1999	2,009	3,589	871	6,469	314	2,409	2.69
2000	2,217	3,173	816	6,206	273	3,320	1.87
2001	2,560	3,214	637	6,411	202	2,702	2.37

The totals in the table are for treatment of the marginal areas found in two 23-km² areas in each year.

^a The areas were treated each year using two permanent and one or two temporary employees of the Southern Insect Management Research Unit, USDA-ARS, Stoneville, MS. Labor costs varied from \$40 to \$54 per hour.

^b Trimec (1999) or Strike 3 (2000 and 2001) were the herbicides used.

^c Calculated using the Mississippi State Budget Generator for development of cost of production estimates (Laughlin 1999). A description of the application equipment and herbicide rates used is found in Snodgrass et al. (2005).

^d The total cost in each year divided by the no. of hectare of cotton protected (the estimated no. of hectare of cotton found in the two treated areas each year).

Table 3. Grower costs and savings in dollars for tarnished plant bug control with insecticides in cotton grown in 23-km² areas of the Mississippi Delta in which broad leaf weeds in marginal areas were controlled with a herbicide in March or April compared with the cost of plant bug control in cotton grown in untreated 23-km² areas

Year	Treated areas				Untreated areas				
	No. growers	Mean no applications	Mean cost/ha ^a	No. growers	Mean no. applications	Mean cost/ha	Cost/ha difference	Insecticide cost savings ^b	Net savings ^c
1999	6	0.9	22.50	14	1.7	38.48	15.98	38,496	32,027
2000	18	3.1	57.95	4	3.8	77.24	19.29	64,053	57,847
2001	11	5.5	93.09	9	7.0	101.59	8.50	22,967	16,556
Mean	12	3.2	57.85	9	4.2	72.44	14.59	41,839	35,477

^a Includes insecticide application and material costs.

^b Cost per hectare difference in insecticides used in cotton for plant bug control in the check areas compared with the treated areas multiplied by the no. of hectare of cotton protected (Table 2).

^c Insecticide cost savings in the treated areas minus total cost of the early season herbicide treatment (Table 2).

higher numbers of plant bugs in cotton in the untreated sites indicated that short range migration from wild hosts could be important in infestation of cotton by plant bugs. Several authors (Tugwell et al. 1976, Cleveland 1982, Anderson and Schuster 1983, Snodgrass et al. 1984, Fleischer and Gaylor 1987) have listed wild hosts on which plant bugs can buildup and be available to move into cotton in the southeastern United States. Fleischer et al. (1988) studied movement of tarnished plant bugs in cotton after destruction of nursery plots of *E. annuus* or mustard, *Brassica juncea* L. Cosson. They found that adult movement in cotton was well fit by a diffusion model. Adults had a strong tendency to move through cotton and emigrate from it to other more attractive hosts if they were available. This suggested that refuges of attractive weedy hosts could be used to help lower plant bug numbers in cotton. However, additional research on this potential control method for tarnished plant bugs in cotton has not been conducted.

It is not known how far and how rapidly tarnished plant bugs migrate from one host to another. As hosts decline in quality (finish blooming), plant bugs will move to other hosts that have flower buds or are in bloom. This movement is critical to the survival of this species. It also determines how rapidly plant bugs will infest crops, and in this study, how big an area must be treated to reduce numbers of wild hosts and delay plant bug population buildups. The size of the treated sites in our study was not based on knowledge of plant bug movement. Rather, they were the biggest areas we could treat and sample logistically. There is one report of tarnished plant bugs being captured in a light trap located 5 km off shore at night (MacCreary 1965). To reach the light trap, the flight had to be sustained because no other land masses were near the trap. Stewart and Gaylor (1991) found that reproductive tarnished plant bug females were most inclined to migrate to new host patches. Using a flight mill, they also found that reproductive females made most of the long-duration flights, with cumulative flight durations seven times greater than those without eggs (Stewart and Gaylor 1994). The ability of the tarnished plant bug to fly with a full complement of eggs allows it to rapidly reproduce on new hosts. Mark and recapture studies that provide data on plant bug movement are

needed for development of noninsecticidal control measures for this pest. The current problem in recapturing marked adults could be partly solved if a trap with a synthetic pheromone was available. However, the sex pheromone produced by female tarnished plant bugs has not been identified.

The lower numbers of tarnished plant bugs found in cotton in the treated test sites were reflected in insecticide control costs. These costs were lower and fewer applications were made in cotton grown in the treated test sites in all 3 yr (Table 3). This is important because it showed that the lower numbers of plant bugs found in cotton in the treated test sites could have been the result of the herbicide treatment, not higher insecticide use in the treated sites. The higher insecticide use for plant bug control in cotton grown in the untreated test sites decreased numbers of plant bugs available for sampling and decreased sample mean values. This probably made it more difficult to find statistical differences in mean comparisons between plant bug numbers found in cotton in the treated and untreated test sites. However, the main problem was only having two replications of each treatment each year. Two replications of each treatment were all that were possible because of cost and time restraints encountered in treating the areas and sampling cotton. Weather in March and April often made herbicide application difficult because of wind and/or rain. Sampling a large number of cotton fields on a weekly basis was also difficult because of rain, irrigation, and insecticide treatments of fields. Because most of the variability (79% of the total) in the data were caused by sample to sample variability, the large number of samples taken in cotton were needed.

Growers in the treated sites spent an average of \$14.59/ha less for plant bug control over the 3 yr of the study compared with growers in the untreated sites. This was a considerable savings in costs because an estimated average of \$35,477 in net savings in the treated sites was found per year over the 3 yr of the study. The highest plant bug populations occurred in 2001. In this year, large numbers of plant bugs were found in cotton throughout the Delta during July and August, and the difference in control costs for plant bugs between cotton grown in the treated and untreated sites was the smallest of any year (Table 3).

In summary, the study showed that control of early season broadleaf weeds in marginal areas resulted in lower numbers of tarnished plant bugs in cotton grown in the treated areas. More importantly, treatment of marginal areas with a herbicide resulted in fewer insecticide applications and lower control costs in cotton grown in the treated test sites. The herbicide treatment will not by itself control plant bugs in cotton, but it could be an important component of an integrated control program for plant bugs that included other noninsecticidal control measures. It is currently the only noninsecticidal control measure for tarnished plant bugs in cotton available for use by producers.

Acknowledgments

We thank D. Adams, C. Lanford, A. Patterson, and J. Cambell for technical assistance and D. Boykin for assistance with statistical analyses.

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Received for publication 28 October 2005; accepted 21 June 2006.